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Even Between-Lap Pacing Despite High Within-Lap Variation During Mountain Biking

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Purpose: Given the paucity of research on pacing strategies during competitive events, this study examined changes in dynamic high-resolution performance parameters to analyze pacing profiles during a multiple-lap mountain-bike race over variable terrain. ***Methods:*** A global-positioning-system (GPS) unit (Garmin, Edge 305, USA) recorded velocity (m/s), distance (m), elevation (m), and heart rate at 1 Hz from 6 mountain-bike riders (mean ± SD age = 27.2 ± 5.0 y, stature = 176.8 ± 8.1 cm, mass = 76.3 ± 11.7 kg, VO_{2max} = 55.1 ± 6.0 mL · $kg^{-1} \cdot min^{-1}$) competing in a multilap race. Lap-by-lap (interlap) pacing was analyzed using a 1-way ANOVA for mean time and mean velocity. Velocity data were averaged every 100 m and plotted against race distance and elevation to observe the presence of intralap variation. ***Results:*** There was no significant difference in lap times (P = .99) or lap velocity (P = .65) across the 5 laps. Within each lap, a high degree of oscillation in velocity was observed, which broadly reflected changes in terrain, but high-resolution data demonstrated additional nonmonotonic variation not related to terrain. ***Conclusion:*** Participants adopted an even pace strategy across the 5 laps despite rapid adjustments in velocity during each lap. While topographical and technical variations of the course accounted for some of the variability in velocity, the additional rapid adjustments in velocity may be associated with dynamic regulation of self-paced exercise.

Keywords: off-road cycling, multiple laps, terrain, teleoanticipation, self-paced exercise

Pacing has been described as the distribution of workload throughout a race or event.[1] Appropriate distribution of energetic resources is considered vital to successful completion of an event in the shortest possible time[2] while preventing potential catastrophic failure that could occur if resources were completely depleted.[3,4]

Much research on pacing strategies of cyclists focuses on the distribution of power during time-trial performances.[5–10] In a stable environment a constant distribution of workload is considered optimal,[6] a finding supported by Foster et al,[7] who determined that an even pace over a 2-km time trial resulted in the most optimal performance compared with either a negative or a positive strategy. For environments where conditions are less stable, mathematical modeling has indicated that a variable pacing strategy where power output is altered in response to hilly and windy conditions can lead to significant time reductions due to achievement of the ideal state of maintaining a constant speed.[5,8,9]

Laboratory- and field-based research has observed a stochastic variation in power output and heart rate during exercise. Palmer et al[11] observed nonmonotonic variation in heart rate that was not related to changes in terrain during a 4-day cycling race, while Tucker et al[10] observed nonmonotonic oscillations of power output with multiple frequency peaks during a self-paced 20-km time trial. During marathon running, high variability in both heart rate and speed with reduced variability in the second half of the race due to fatigue has also been observed.[12]

Few studies have investigated pacing strategies in multiple-lap events. Ansley et al[13] identified nonmonotonic variations in power output, iEMG activity, and oxygen uptake in 3 successive 4-km time trials and suggested that this variation was evidence for the dynamic regulatory activity of pacing. Although time-trial performance was significantly slower in the second than in the first trial, the third trial was not significantly different from the first and thus indicates that an overall pacing strategy was in operation. In the field, high-resolution data (1 Hz) during the cycling phase of Olympic-distance[14] and Ironman[15] triathlon have demonstrated a high variation in power output within each lap of multilap courses. In the shorter distance, Bernard et al[14] reported increased

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variation in power output as mean power decreased as the cycle phase progressed, whereas in the Ironman distance, Abbiss et al[15] reported that the high degree of oscillation in power output for each lap was maintained even though performance time increased for each lap. The maintenance of high intralap variation was thought to be evidence of a nonlinear dynamic pacing strategy.[15]

Cross-country mountain-bike racing has been described as a mass-start endurance event consisting of repeat laps of an off-road circuit.[16] Racing in an unstable environment with frequent changes in surface and gradient requires a high degree of technical competency. It was considered important, therefore, to determine whether a general pacing strategy or a lap-by-lap strategy was adopted and whether the fidelity of this strategy was maintained in an unstable environment. The aim of the current study was to analyze pacing profiles during cross-country mountain biking through examination of velocity data captured at a high frequency over a multiple-lap mountain-bike race.

Methods

Subjects

Five male and one female senior-category (19 y plus) riders with at least 1 year of competitive riding experience volunteered to participate in the study. All riders were competitors in a regional mountain-bike cross-country racing series, and data were collected at one of these races. Participants were fully informed of the procedures and associated risks of the study, completed a pretest health questionnaire, and provided written informed consent before commencement of the testing. Ethical approval for this study was granted through the institutional ethics committee.

Design

The study was a single observational field trial examining athletes under race conditions.

Methodology

The mountain-bike race occurred over a 4.5-km course of varying terrain with a total ascent and descent of 237 m/lap. The course comprised both single track (56% of lap distance) and twin tracks (24%) on a range of surfaces including loose peat soil, grass, gravel, compacted sand, and tarmac. All participants competed at the same time over 4 laps for women and 5 laps for men.

A global-positioning-system (GPS) unit (Garmin, Edge 305, USA) was fitted to the handlebars of each bicycle and programmed to record velocity and heart rate at 1-second intervals. Peterson et al[17] and Jennings et al[18] have reported poor measurement reliability of GPS units at 1 Hz over short sprints but good reliability over longer distances at slower velocities during multidirectional exercise. While the course was curvilinear rather than multidirectional, there may be an underestimation of higher-intensity activity where rapid changes in speed occurred.

Participants completed a self-selected warm-up before the start of the race. They raced to the best of their ability and received no instructions in relation to pacing or racing strategy from the research team. On completion of the race, GPS data were downloaded using the Garmin Training Center (Garmin, USA) software and exported into Excel (2007, Microsoft Corp, USA) for analysis.

Statistical Analysis

As in other studies analyzing pacing strategies,[10] visual observation of changes in velocity collected at high resolution was used to analyze pacing profiles for each lap. Velocity data (m/s) were used to calculate mean ± SD velocity for each lap and mean ± SD overall race velocity. Velocity data (m/s) were averaged every 100 m and plotted against race distance and elevation to observe the presence of variation within each lap. To assess variability, the range of velocities used by each participant was determined by portioning the velocities into 1-m/s bins and subsequently counting the frequency of data points (1-s intervals) in each velocity bin for each lap. Heart rate was averaged over the entire race. A 1-way ANOVA was undertaken to compare mean time and mean velocity across each of the laps. A significance level or $P \leq .05$ was accepted and a Tukey post hoc test used as required. In all analyses, results for lap 5 represent data from the 5 male riders only.

Results

Participant characteristics were (mean ± SD) age 27.2 ± 5.0 y, stature 176.8 ± 8.1 cm, and mass 76.3 ± 11.7 kg. Exercise intensity of the race was high, with an average heart rate of 171 ± 8 beats/min (91% ± 2% HR_{max}).

Overall race time (min:s) was 100:42 ± 26:10 with an average velocity of 3.9 ± 0.19 m/s. Figure 1 illustrates that there was no significant difference in time (min:s) to complete each lap (lap 1, 21:52 ± 4:15; lap 2, 21:48 ± 3:07; lap 3, 21:56 ± 3:06; lap 4, 22:31 ± 3:02; lap 5, 22:10 ± 2:38; $P = .997$). Similarly, there was no significant difference in the mean velocity across laps (lap 1, 4.18 ± 0.59 m/s; lap 2, 3.94 ± 0.54 m/s; lap 3, 3.91 ± 0.56 m/s; lap 4, 3.72 ± 0.52 m/s; lap 5, 3.72 ± 0.54 m/s; $P = .65$).

Riders used a wide range of velocities during each lap (0–11 m/s). The frequency histogram of velocities used reflected a Gaussian distribution (Figure 2).

Average velocity (per 100 m) of the participants for each lap and course elevation is displayed in Figure 3. A relationship can be observed between the changes in velocity and elevation (Figure 3A and 3B), but due to the technical demands of the course a decrease in elevation did not always lead to an increase in velocity. Similar trends can also be seen in Figure 4, which illustrates data from 1 participant at the higher capture rate of 1 Hz but also shows a large degree of nonmonotonic variation throughout, which sometimes changes independently of elevation.

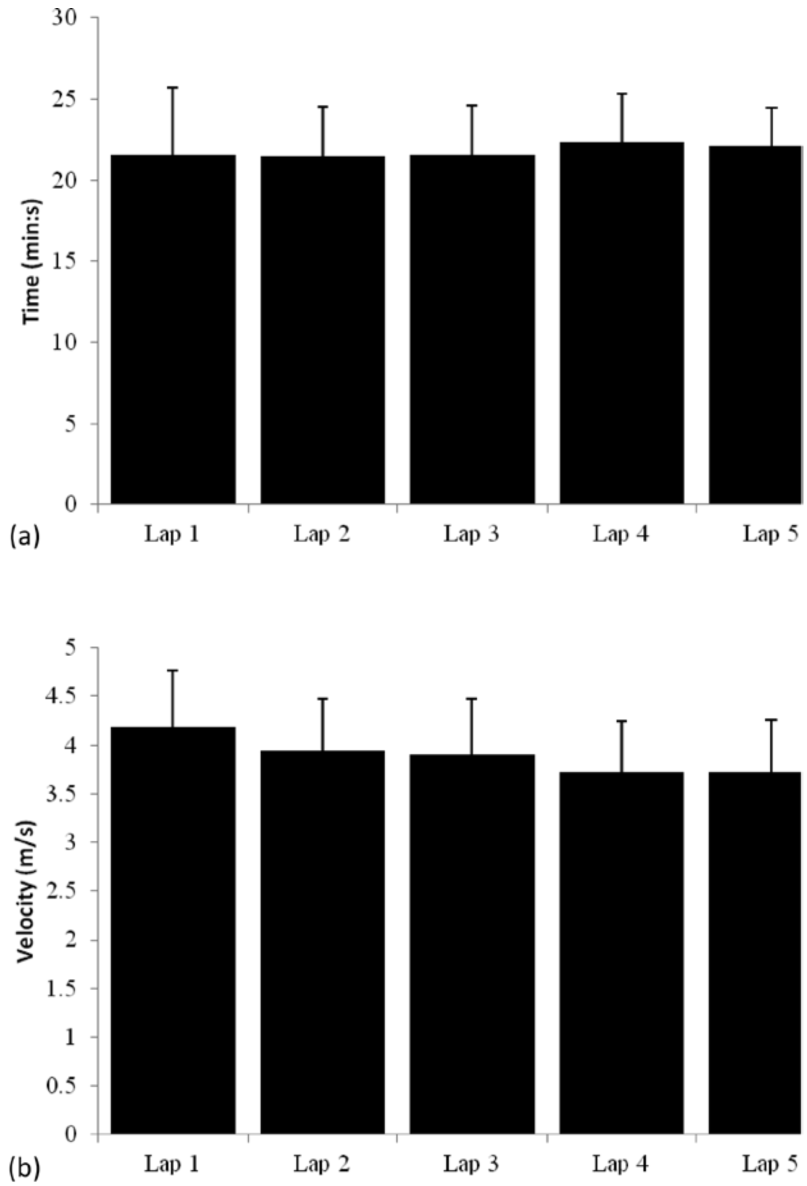

Figure 1 — (a) Time and (b) velocity per lap, mean ±SD.

Highest race velocities were recorded on the first lap from 0 to 700 m. Peak velocity, recorded at 600 m, was faster, but not statistically significantly, during the first lap than the remaining laps (lap 1, 7.39 ± 0.16 m/s; lap 2, 6.45 ± 0.38 m/s; lap 3, 6.44 ± 0.25 m/s; lap 4, 6.54 ± 0.22 m/s; lap 5, 6.12 ± 0.24 m/s). After 600 m, there was a similar pattern of variability in velocity across all laps (Figure 3).

Discussion

The purpose of this study was to identify and assess pacing profiles during real competition in an unstable environment. The data present 3 noteworthy findings. First, overall an even between-lap pacing strategy, evidenced by almost identical lap times and pace profiles, was adopted despite the high variability of velocity during a single lap. Second, the data generally reflect a spontaneous relationship between pacing and course terrain. Third, high-resolution data were remarkably similar for each lap and illustrate that velocity varies at a very high frequency and occasionally independently of the changes in elevation. It appears, therefore, that a very robust interlap and intralap pacing strategy that is not completely related to terrain was adopted throughout the event.

It is remarkable to observe that an even between-lap pacing strategy was adopted (Figure 1), given the unstable nature and technical demands of the course. It has been

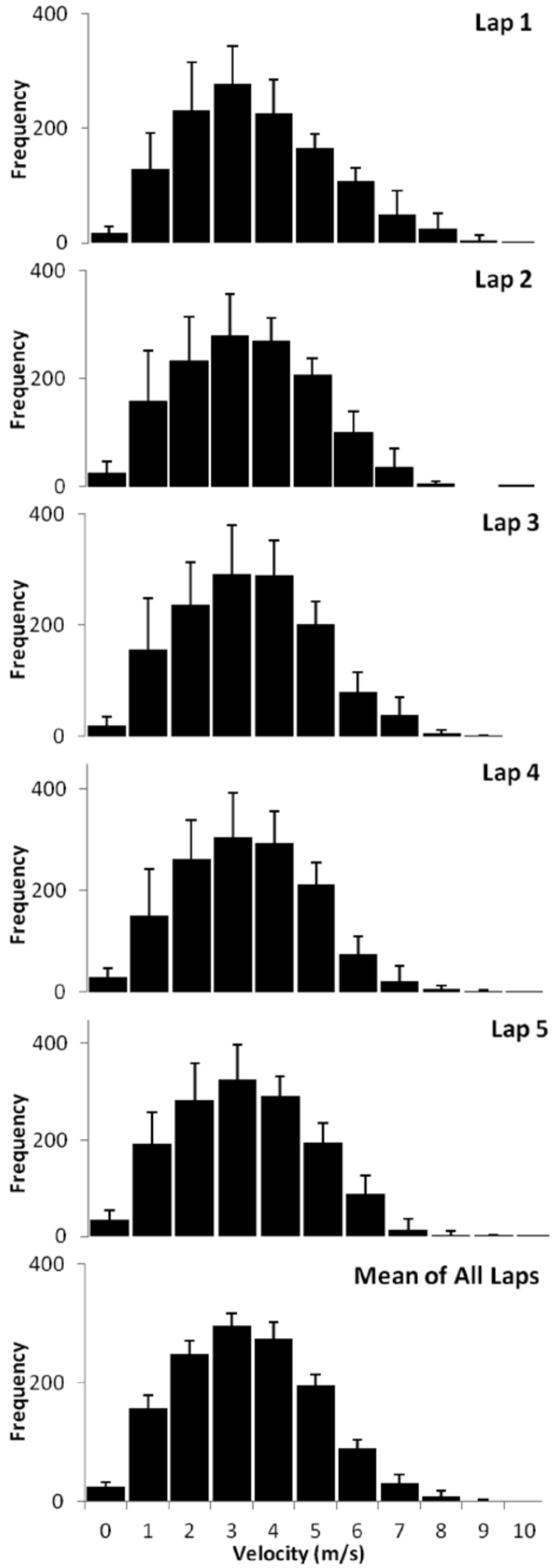

Figure 2 — Frequency histograms of the velocity data of all participants for each of the 5 laps and the mean (± SD) data of all laps.

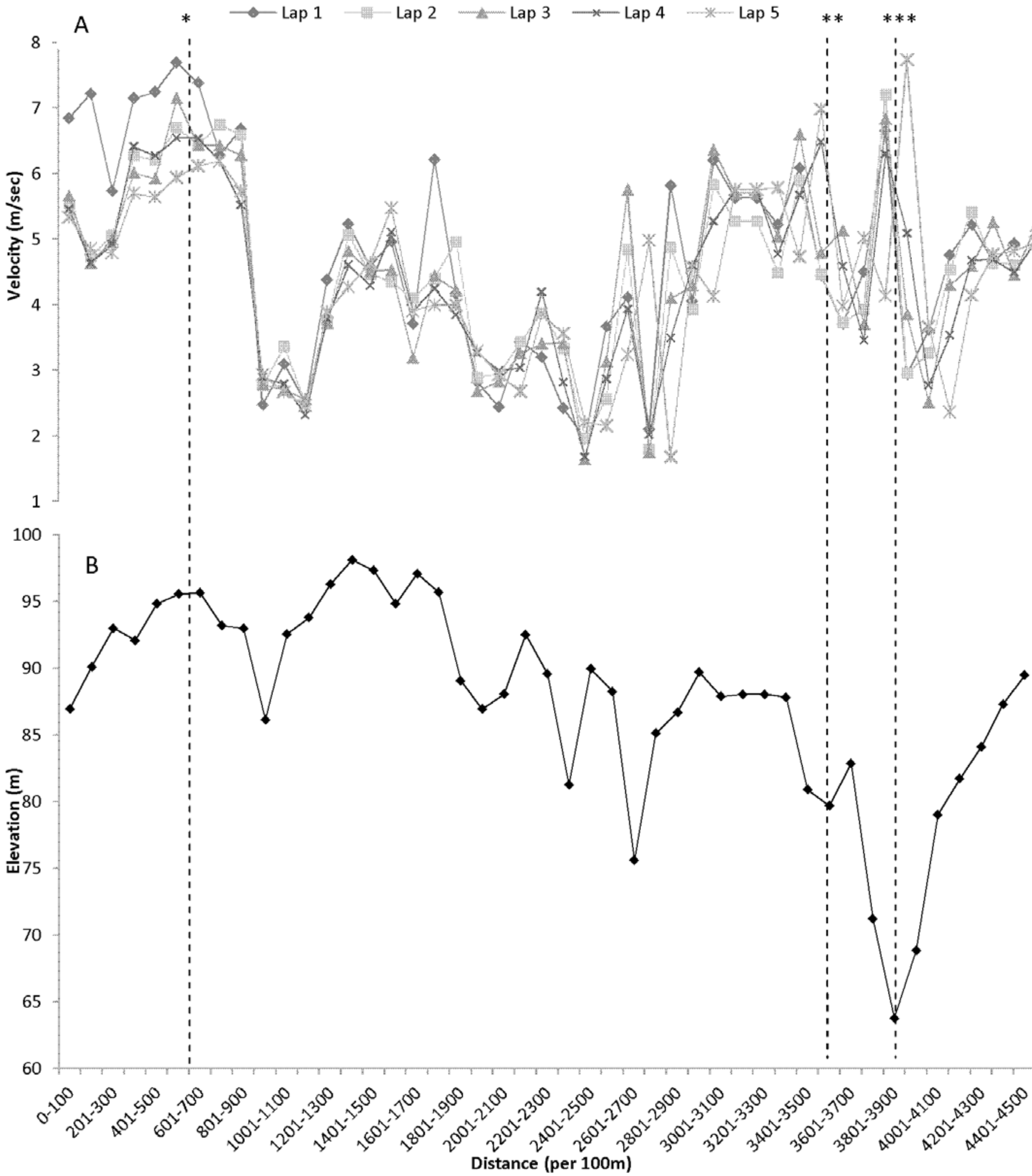

Figure 3 — (A) Mean velocity per 100 m, per lap for all participants and (B) elevation (m) for 1 lap. Note the varied relationships between changes in velocity and elevation: *A large decrease in velocity with decreasing elevation, **an increase in velocity with decreasing elevation, and ***an increase in velocity with an increase in elevation.

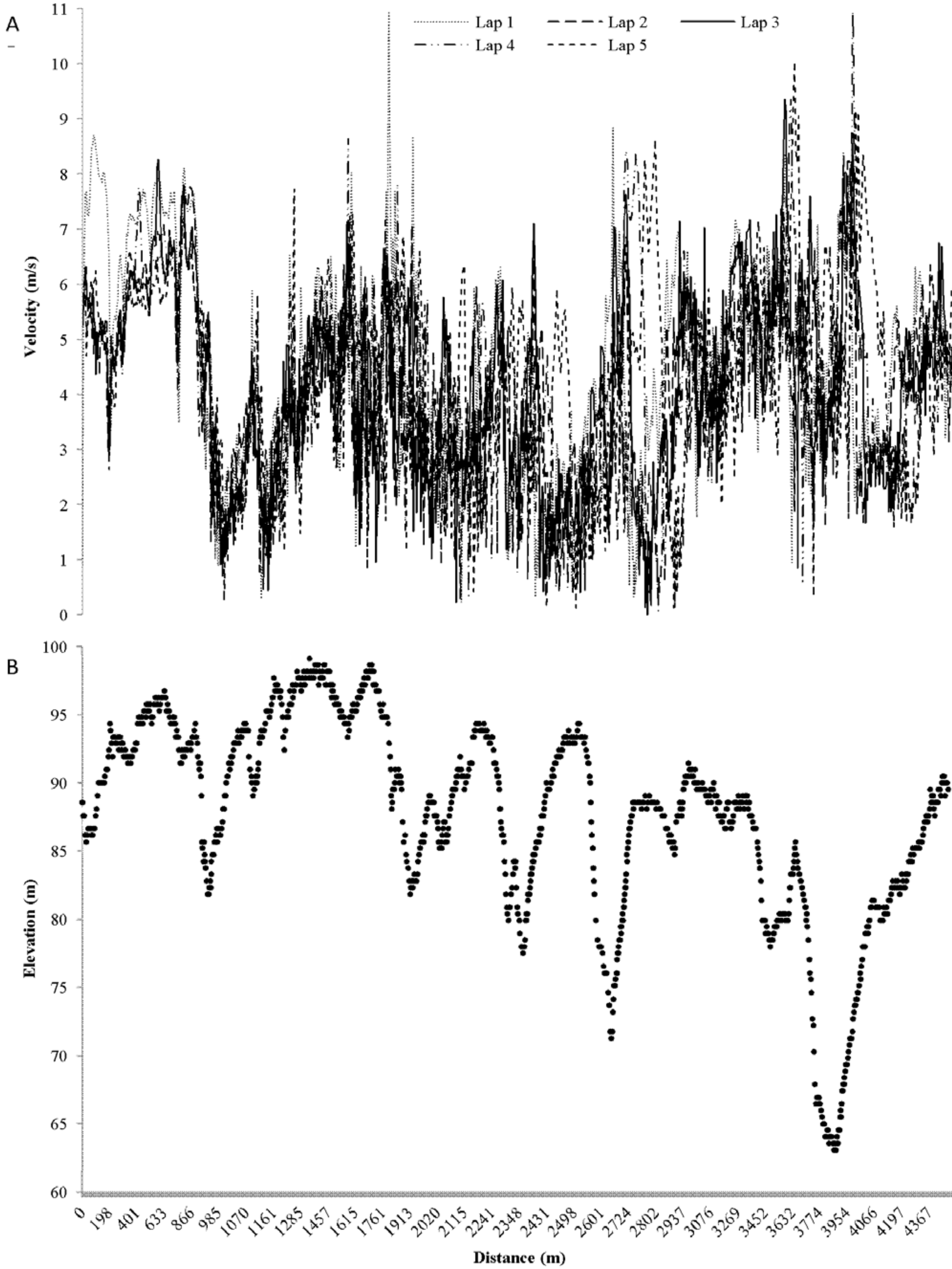

Figure 4 — High-frequency data (every 1 s) for 1 participant displaying (A) velocity over 5 laps and (B) the elevation of the course for 1 lap.

suggested that for prolonged events under stable conditions a constant pace is optimal.[19] The current study took place in conditions that were topographically unstable and technically challenging and yet supports the existing laboratory, track, and road cycling research, which have all reported the adoption of even pacing strategies.[2,7,20–22] Furthermore, few studies have considered the pacing of multiple-lap events. Abbiss et al[15] reported a significant decrease in power output, cadence, and speed during the 3-lap cycling phase of an Ironman triathlon, demonstrating a positive pacing strategy. During the shorter cycling phase of an Olympic triathlon, a significant decrease in power output and velocity has also been observed.[14] Our findings are in direct contrast to this, with no significant difference in lap time or lap velocity across multiple laps (Figure 1). This difference likely reflects the specific pacing strategies of a multievent sport such as triathlon, in which competitors typically complete the opening phase of the cycle at a fast pace to position themselves within the peloton of riders so that drafting can take place for energy conservation.[14] As the cycle phase ends, competitors may further reduce their power output as a deliberate strategy to prepare themselves for the run element in an optimal condition.[14] In contrast, the narrow tracks, sharp turns, and rapid changes in elevation of cross-country mountain biking are less conducive to overt tactical pacing.

The maintenance of an overall velocity across all laps (even pace) suggests that there has been close regulation of power output from active muscles to maintain pace to the endpoint of the race. If fatigue is viewed as an unavoidable decline in exercise performance due to the decreased ability to produce force,[23] then there must have been anticipatory planning at the outset.[3,4,24] To our knowledge all of participants completed a practice lap of the course. This familiarization alongside information relating to experience, technical skills, environmental conditions, motivation, fellow competitors, and knowledge of the endpoint of the race will all have enabled processes in the brain to calculate the required intensity needed to complete the race in the fastest possible time. Baden et al[25] state that these anticipatory mechanisms, previously described as teleoanticipation, focus on the endpoint of the task and work backward from that point when regulating optimal metabolic rate and motor output. Furthermore, St Clair Gibson et al[26] suggest that for athletes to reach this endpoint in the fastest possible time while maintaining sufficient metabolic capacity to avoid stopping before the finish, they require some form of pacing strategy that must take this endpoint strategy into consideration. The data in this study suggest that an even pacing strategy was adopted across the 5 laps, as there was no statistically significant difference in average velocity ($P = .65$). The current study therefore lends support to the existing literature suggesting that the pacing strategy adopted during self-paced exercise is anticipatory, based on the expectation of the exercise duration and other pertinent factors.[4,27–29] It is astonishing that, given the many factors that could have influenced velocity over the duration of the event, similar lap pacing profiles were produced, resulting in the similar lap times.

The data from the current study generally support evidence of a spontaneous relationship between terrain and velocity (Figure 3). However, due to the technical demands of the course, the achievable velocity of any given ascent or descent is limited, and in some situations the expected relationship is inverted. For example, between 600 and 900 m there was a decrease in mean velocity from 6.59 ± 0.48 to 2.77 ± 0.18 m/s despite a descent in elevation from 95.65 to 86.15 m, as compared with between 3600 and 3900 m, velocity increased from 4.23 ± 0.62 to 6.23 ± 1.21 m/s during a descent in elevation (82.86 to 63.78 m). In the former, velocity slowed because riders had to negotiate a sharp right-hand turn at the bottom of the loose peat descent, whereas they were able to increase velocity over the second descent, which occurred on wider grass track. Similarly, there were occasions when despite an increase in elevation there was an increase in velocity. For example from 3800 to 4500 m, elevation increased from 63.78 to 89.48 m and velocity increased from 3.17 ± 0.51 to 5.05 ± 0.14 m/s as riders increased their efforts on the wider tarmac section of the course that led into the start/finish area (Figure 3). Similar oscillations in power output have previously been reported.[30] Differences in rider experience, technical competency, and risk tolerance may further affect the resultant velocity at any given part of the course and partly explain differences between individual riders.[16,31]

Figure 2 illustrates that participants used a wide range of velocities (0–11 m/s) within each lap. It is not unusual for riders to put a foot down or slow to a temporary stop when negotiating technical elements of the course, resulting in the recording of ≤1 m/s. The pattern and distribution of velocities used were notably consistent in all laps. Using a wide range of velocities is in marked contrast to the proposed ideal state of a constant velocity that is thought to be optimal in cycling time trials.[9] Pacing strategies derived from mathematical models suggest that this constant velocity can be achieved by varying power output in response to changes in gradient and wind. More specifically, power output should increase during ascents and headwinds and decrease during descents and tailwind sections.[5,8,9] Abbiss et al[15] reported no significant difference in power output or cadence between headwind and tailwind sections of the cycle phase of an Ironman triathlon. During mountain biking, Stapelfeldt et al[30] reported a coefficient of variation of 69% with a mean power output of 208 W and observed that high oscillations in power output reflected not only the profile of the course but also the demands of the course, with high- and low-power outputs being observed during technical turns. In cross-country mountain biking the varying terrain (grass, peat, gravel, etc) and the additional technical demands of the course to negotiate tight bends and obstacles (eg, tree roots) make this constant workload far more difficult to achieve. Nevertheless, it appears that, for the race as a whole (between-lap variability), even pacing has been achieved, albeit via the use of an extensive range and high variability of velocity within each lap. Therefore, it appears that the theoretical pacing strategies proposed for time-trial cycle events are also appropriate for cross-country mountain biking. These events have a similar duration and intensity despite occurring in very different environments, and a robust interlap strategy to achieve an overall "constant" velocity to complete the event in the fastest possible time while maintaining physiological homeostasis appears to be predominant.

High-frequency data capture is required to observe the nonmonotonic changes in power output and other physiological variables that are considered to represent the dynamic neural control of self-paced exercise.[10] Traditional low-frequency data provide only snapshots and typically illustrate decrements in power output and other variables over time.[32] Our high-resolution data (Figure 4) illustrate extremely frequent changes in velocity throughout the race that were sometimes independent of the changes in terrain. Baden et al[25] proposed that constant adjustments in the pacing strategy occur throughout exercise via afferent and efferent communication between the brain and working muscles. Tucker et al[10] observed a high variation in power output during a 20-km laboratory time trial. Fractal analysis of the data revealed a number of dominant frequencies, which they suggested to be evidence of multiple feedback loops from different regulatory systems responsible for the continuous modification of muscle power output during self-paced exercise.[10] It is conceivable, therefore, that the more rapid high variability of velocity observed in the current study (Figure 4) is controlled in the same manner and is evidence of the regulation of pacing that enables each participant to make continuous tactical adjustments to complete the race in the fastest possible time at a sustainable metabolic rate. This resulted in the very similar lap times despite the observed intralap variation in velocity. Further evidence of pacing in the current study can be inferred from the fast pace observed after the mass start of the race (0–700 m, lap 1). All participants recorded their highest velocities of the race at 600 m on lap 1, and this observation is similar to the significantly higher peak power output recorded in the first of 3 successive 4-km cycling time trials reported by Ansley et al.[13] While the critical nature of a mass start demands an initial high speed by competitors, the degree of acceleration achieved by each rider will reflect his or her individual fitness, experience, motivation, fatigue, and prior knowledge of the course and competitors commensurate with his or her own overall riding ability and, as such, is regulated by teleoanticipation. The complex internal regulation systems then provide afferent feedback, which, along with the knowledge of the endpoint, could be used to make suitable adjustments in pace and allow the rider to select an appropriate intensity to maintain for the remaining laps, without any physiological systems deviating too far from homeostasis. In the current study all riders demonstrated acceleration at the start of the race and then settled into a reduced pace with high variability that was similar between laps and maintained for the duration of the race. Ulmer[4] states that as part of the teleoanticipation process, early fatigue acts as a safety mechanism, which initiates decrements in exercise intensity before an accumulation of metabolite or energy-store depletion occurs, which would explain the reduction in pace after the fast start. In a mass-start event, it is possible that some athletes' pacing will be influenced by the presence of other riders or spectators around them, resulting in a higher speed that may not be sustainable for the duration of the race. In this situation, high velocity followed by much slower velocities in later laps as a consequence of fatigue is likely to occur. Our data set does not evidence this, indicating that the participants in the current study were not externally influenced in their pacing.

A limitation of this study is the small heterogeneous sample. While only 6 of the recruited participants competed in the race reported here, previous studies have clearly demonstrated the robustness of pacing.[27] In addition, since the data are reported over a 5-lap race (4 laps for women) they represent 29 individual laps in which high intralap variability has been observed. A second limitation is that power was not measured. While power has primarily been used in previous pacing studies of time-trial cycling, in the unstable and competitive environment of the current study we suggest that power output is not the only determinant of pacing and therefore cannot fully explain the observed variability in velocity during each lap of the race. Environmental conditions, rider experience, technical ability, resistive forces, motivation, mood, nutritional status, spectators, and more influence pacing. Since velocity is the resultant product of all of these factors, it provides a more holistic insight into pacing than power alone.

Practical Applications

While additional research during competition is needed to confirm our findings, it would appear that due to the robustness of the pacing strategy, coaches and athletes should focus on increasing speed for each lap to improve overall performance. Further research could also consider how course familiarization and practice laps affect pacing profiles during competition.

Conclusions

To our knowledge, this is the first article to analyze a multiple-lap race over varying and undulating terrain. The data illustrate 3 critical findings. First, participants demonstrated a variable intralap pacing profile in response to the topographical and technical demands of the course, but overall, an even interlap profile was adopted, suggesting that pacing was anticipatory in nature. Second, the data generally evidence a spontaneous relationship between pacing and terrain. Finally, high-resolution velocity data illustrate that velocity varies at a very high frequency independent of changes in terrain. It is highly likely that these rapid adjustments in velocity are the result of dynamic regulation of self-paced exercise.

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